

Understanding the Forward Muon Deficit in Coherent Pion Production

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Abstract. For any inelastic process $\nu_\ell + I \rightarrow \ell^- + F$ with $m_\ell = 0$, the cross section at $\theta_\ell = 0$ is given by Adler's PCAC theorem. Inclusion of the lepton mass has a dynamical effect ("PCAC-screening") caused by interference of spin-zero (π^+) and spin-one exchanges. This effect may be relevant to the forward suppression reported in recent experiments.

Recent experiments with low energy neutrino beams suggest that in inelastic CC events, there are fewer muons coming out at small angles than expected. (For a review of the data, see the talk of Bonnie Fleming) [1]. The evidence comes principally from two-track events that are interpretable as $\nu_\mu + (p, n) \rightarrow \mu^- + (p, n) + \pi^+$ with nucleon undetected, or coherent π^+ production $\nu_\mu + \text{Nucleus} \rightarrow \mu^- + \pi^+ + \text{Nucleus}$. In particular, the K2K experiment ($E_\nu \approx 1.3 \text{ GeV}$) has reported a deficit at low Q^2 ($Q^2 < 0.1 \text{ GeV}^2$) which they interpret as a suppression of coherent π^+ , obtaining an upper limit $\sigma(\text{coh } \pi^+)/\sigma(\text{CC}) < 0.6\%$ [2], compared with a theoretically expected value of 2% [3].

The deficit is puzzling since there appears to be evidence for NC coherent π^0 production $\nu_\mu + \text{Nucleus} \rightarrow \nu_\mu + \pi^0 + \text{Nucleus}$ [4] at roughly the expected rate $\sigma(\text{coh } \pi^0)/\sigma(\text{CC}) \approx 1\%$, and a ratio $\sigma(\text{coh } \pi^+)/\sigma(\text{coh } \pi^0) = 2$ is expected from fairly general isospin considerations.

This situation has prompted us to ask whether the deficit could be a dynamical effect caused by the nonzero mass of the muon in the CC channel, absent in the NC process. We recall that in any inelastic CC reaction $\nu_\mu + I \rightarrow \mu^- + F, F \neq I$, the cross section in the forward scattering configuration for $m_\ell = 0$ is predicted by Adler's PCAC theorem [5]

$$\left(\frac{d\sigma}{dx dy} \right)_{\theta=0} = \frac{G^2 M E_\nu}{\pi^2} f_\pi^2 (1-y) \sigma(\pi^+ + I \rightarrow F)|_{E_\pi=E_\nu y} \quad (1)$$

For non-forward scattering, this result is expected to be modified by a slowly-varying factor $(1 + Q^2/M_A^2)^{-2}$, where $M_A \approx 1 \text{ GeV}$ is the typical mass of the spin-one (1^{++}) mesons mediating the process. If the muon mass is not neglected, however, the process receives an additional contribution due to the exchange of a spin-zero π^+ meson. It was shown by Adler [5] that the forward theorem is modified by a multiplicative factor,

which may be written as [6]

$$C_{Adler} = \left(1 - \frac{1}{2} \frac{Q_{min}^2}{Q^2 + m_\pi^2}\right)^2 + \frac{1}{4} y \frac{Q_{min}^2 (Q^2 - Q_{min}^2)}{(Q^2 + m_\pi^2)^2} \quad (2)$$

where

$$Q_{min}^2 = m_\ell^2 \frac{y}{1-y} \quad (3)$$

This correction is valid for small angles, and contains the important terms in which the factor m_μ^2 is accompanied by the pion propagator $1/(Q^2 + m_\pi^2)$. The factor C_{Adler} has non trivial consequences for all inelastic cross sections at small angles. For forward scattering, in particular,

$$C_{Adler}(\theta = 0) = \left(1 - \frac{1}{2} \frac{Q_{min}^2}{Q_{min}^2 + m_\pi^2}\right)^2 \quad (4)$$

The minus sign within parentheses indicates that the effect of pion-exchange is a destructive interference. Taking an average value $y \approx 1/2$, the forward suppression factor is

$$C_{Adler}(\theta = 0, y = 1/2) = \left(1 - \frac{1}{2} \frac{m_\mu^2}{m_\mu^2 + m_\pi^2}\right)^2 = 70\% \quad (5)$$

We have investigated [6], the consequences of this screening effect in the coherent process $\nu_\mu + C^{12} \rightarrow \mu^- + \pi^+ + C^{12}$ using the model described in [3]. The effects on $d\sigma/d\cos\theta_\mu$ and $d\sigma/dQ^2$ are shown in Fig. 1 and Fig. 2, and exhibit a forward muon deficit. Note that a comparison of the $m_\mu \neq 0$ and $m_\mu = 0$ cases is essentially a comparison of ν_μ and ν_e scattering, and that a “muon deficit” could equally be regarded as an “electron excess”.

In applying the above suppression mechanism to the K2K data, our analysis [6] indicates that the coherent π^+ signal in the domain $Q^2 < 0.1 \text{ GeV}^2$ is suppressed by a factor $\langle C_{coh} \rangle \approx 0.77$. We have also estimated the incoherent resonant background, using the resonance model [7], and obtain a suppression factor $\langle C_{res} \rangle \approx 0.85$. These results allow a reinterpretation of the K2K deficit in the interval $Q^2 < 0.1 \text{ GeV}^2$, and reduce the discrepancy to about 2σ . A detailed discussion of muon mass effects will appear in [8].

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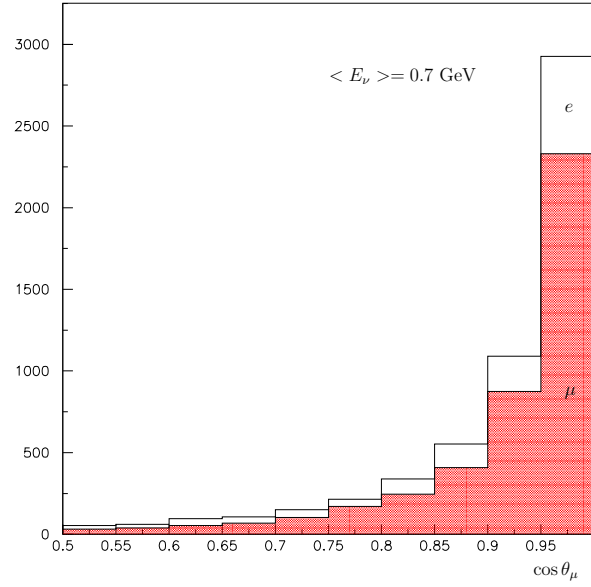


FIGURE 1. Muon mass corection in $d\sigma^{coh}/d \cos \theta_\mu$ for MiniBoone energy $\langle E_\nu \rangle = 0.7 \text{ GeV}$

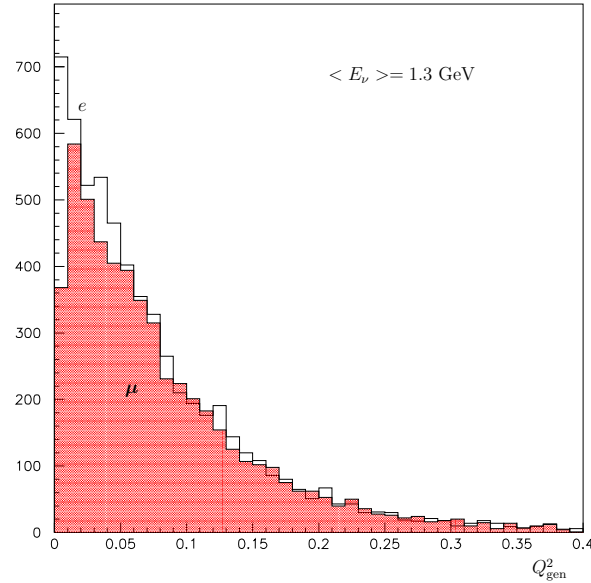


FIGURE 2. Muon mass correction in $d\sigma^{coh}/dQ^2$ for K2K energy $\langle E_\nu \rangle = 1.3 \text{ GeV}$